

## **Models of Acoustic Wave Scattering @ 0.2 – 10 Khz from Turbulence in Shallow Water and Their Applications to ASW Sonar**

Dr. Tokuo Yamamoto  
AMP Division, RSMAS,  
University of Miami, Miami, FL 33176.  
305-421-4637 (TEL), 305-421-4701 (FAX) [tyamamoto@rsmas.miami.edu](mailto:tyamamoto@rsmas.miami.edu)

Award Number N000140810322.

### **LONG TERM GOAL**

The NRL team have been and also planned to acquire the broadband and low frequency propagation data through sediments (Turgut, 2009). This rich supply of propagation data will allow Professor Yamamoto to further investigate effect of the pore space distribution on the dispersion of acoustic wave if the Professor Yamamoto's effort will be funded.

### **OBJECTIVES**

Determine the power spectrum of the scattered acoustic wave by turbulence is given by,

$$[10 \log (d\sigma)] = 10 \log (0.030k^{1/3}V/r \left[ \frac{C_v^2}{c^2} \cos^2 \frac{\theta}{2} + 0.13 \frac{C_T^2}{T^2} \right] \left( \sin \frac{\theta}{2} \right)^{-11/3} d\Omega)$$

### **APPROACH**

Coherent and incoherent analyses

Sound transmission signals in the ocean are largely affected by sea surface and bottom conditions, and sound speed and current velocity fields. If received signals fluctuate around a mean state, we can separate them into the mean and fluctuated components. The temporal coherent method is so useful as a time-series signal separation technique. The separation of signal amplitude  $E(t)$  into the coherent and incoherent parts is performed as follows;

$$E(t) = \langle E(t) \rangle + \delta E(t)$$

$$\langle \delta E(t) \rangle = 0$$

where the angular brackets denote the ensemble average. The received intensity is the sum of the coherent and incoherent intensities and expressed by

$$\langle |E(t)|^2 \rangle = \langle |\langle E(t) \rangle|^2 \rangle + \langle |\delta E(t)|^2 \rangle$$

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 2009</b>		2. REPORT TYPE <b>Annual</b>		3. DATES COVERED <b>00-00-2009 to 00-00-2009</b>	
4. TITLE AND SUBTITLE <b>Models Of Acoustic Wave Scattering @ 0.2 - 10 Khz From Turbulence In Shallow Water And Their Applications To ASW Sonar</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>University of Miami,AMP Division, RSMAS,Miami,FL,33176</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>Code 1 only</b>					
14. ABSTRACT <b>The NRL team have been and also planned to acquire the broadband and low frequency propagation data through sediments (Turgut, 2009). This rich supply of propagation data will allow Professor Yamamoto to further investigate effect of the pore space distribution on the dispersion of acoustic wave if the Professor Yamamoto?s effort will be funded.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES  <b>8</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

We shall here define the total intensity, which is the sum of the coherent and incoherent intensities, as

$$P_{tot}(t) = \langle |E(t)|^2 \rangle$$

The incoherent intensity  $P_{incoh}(t)$ , which may be called the scattered intensity, is given by the relationship

$$P_{incoh}(t) = P_{tot}(t) - P_{coh}(t)$$

In the short-range experiment, the travel time data are significantly biased by ray path fluctuations due to the change of sound speed fields because the effect of path integration forming the travel time data is insufficient for the short-range transmission.

Scattering of Acoustic Waves from Turbulence.

The energy flux density in the incident wave is,

$$S_0 = \frac{1}{2} \omega \rho A_0^2 \vec{k} / r$$

Consequently,

$$d\sigma(\theta) = 2\pi k^4 V / r \left[ \frac{1}{C^2} E \left( 2k \sin \frac{\theta}{2} \right) \right] \cos^2 \frac{\theta}{2} + \frac{1}{4T^2} \Phi_T \left( 2k \sin \frac{\theta}{2} \right) ] d\Omega \quad (5.23)$$

$$E(\kappa) = 0.061 C_v^2 \kappa^{-11/3} \quad (5.27)$$

$$\Phi_T(\kappa) = 0.033 C_T^2 \kappa^{-11/3} \quad (5.28)$$

$$d\sigma(\theta) = 0.030 k^{1/3} V / r \left[ \frac{C_v^2}{c^2} \cos^2 \frac{\theta}{2} + 0.13 \frac{C_T^2}{T^2} \right] \left( \sin \frac{\theta}{2} \right)^{-11/3} d\Omega \quad (5.29)$$

$$C_v \approx 10^{-2} \sim 1 m^{2/3}$$

$$c_0 = 1500(340) m/s \text{ Acoustic Waves}$$

$$C_n = 10^{-9} \sim 10^{-7} m^{-1/3} \text{ EM wave}$$

$$C_n = 10^{-6} \sim 10^{-3} m^{-1/3} \text{ Acoustic Waves}$$

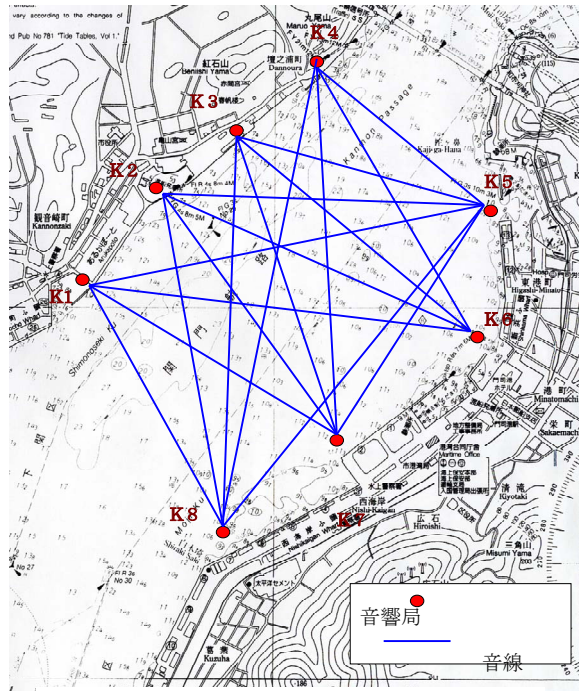
$$C_T = 10^{-3} \sim 10^{-1} \text{ deg}/m^{1/3}$$

$$T_0 = 288^\circ K (20 \text{ deg } C)$$

## WORK COMPLETED

### At-Sea Experiment of Scattering of Acoustic Wave from Turbulence

At-Sea Experiment was conducted in Kanmon Kaikyo (Kanmon Strait), Setonaikai, Japan in March, 2003 by Professor Arata Kaneko and his team of researchers. This experiment was conducted for Current Acoustic Tomography (Kaneko, et al, 2003). The water depth of experimental area is roughly 18 m and the area of 1500 m x 3500 m. The layout of tomography is shown in Figure-2-1. The source level of each of the eight transceivers is 190 dB and modulated by the Gold sequence of 1023 digit.



**D = 18 m**

**Tomo Area  
1.5 km x 3.5 km**

2

**Figure-2-1. The tomography network and location of acoustic sources.**

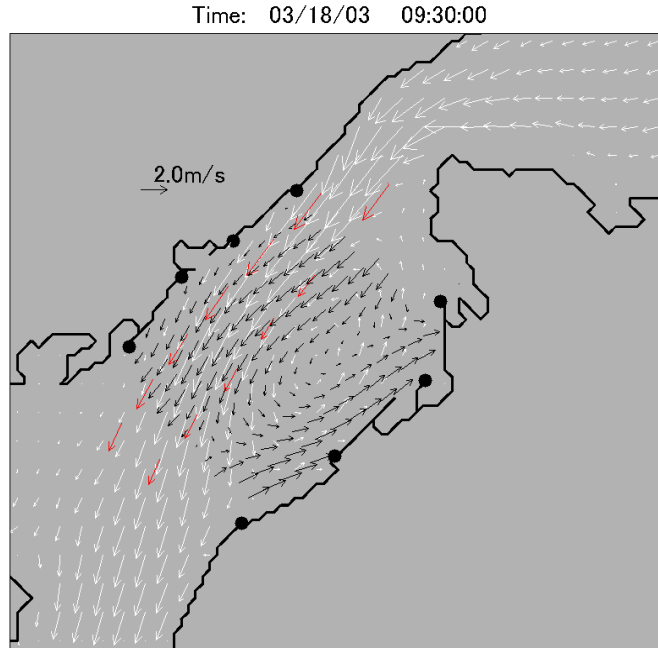
By this we have a 33 dB processing gain and communications from all sources to all receivers without cross talking. The Kanmon Strait opens to the Pacific Ocean to the East and to the Genkai Nada to the West which is located between the Pacific Ocean and the Japan Sea. Therefore, the strait has a large tidal prism of 2.0 m all the time. The strait water is well mixed thus there are no thermoclines. Therefore, the acoustic wave scattering from thermoclines may be ignored when the acoustic wave scattering in the Kanmon Strait is concerned. The Kanmon Data of its entirety was given to Professor Yamamoto for his study of acoustic scattering by turbulence.

## RESULTS

### Data Analysis of Acoustic Wave Scattering by Turbulence.

The large eddy ~ 3 km developed in the tomographic network is shown in Figure-2-2. The time is near high tide so that strong ~ 3 m/s jet flushes the water in the domain. The jet generates a large eddy 3 km

x 1 km in the middle of the tomographic net work. The black arrows show the current speed image obtained by the tomography inversion. White arrows show the current image obtained based on the Princeton Ocean Model (POM) which is corrected by the selected rays of the tomography images through an data assimilation technique.



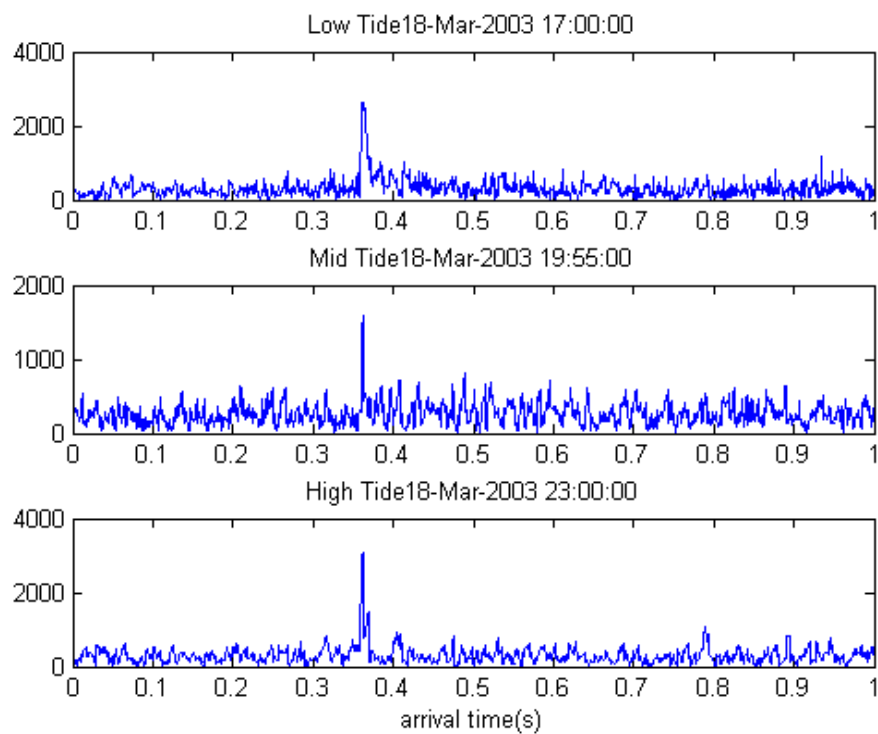
**Figure-2-2. Measured large eddy (~ 3 km) within the tomography area.**  
**Black arrows show the velocity zone measured by tomography inversion.**  
**White arrows show the velocity field calculated by the Princeton Ocean Model (POM) corrected by the velocity fields (selected) obtained by tomography.**

Received signals at different tide heights (K8->K5) are shown in Figure-2-3. Figure-2-4 shows the incoherent, coherent and total intensities of received signal. The coherent intensity signal is very small compared with the incoherent intensity signal.

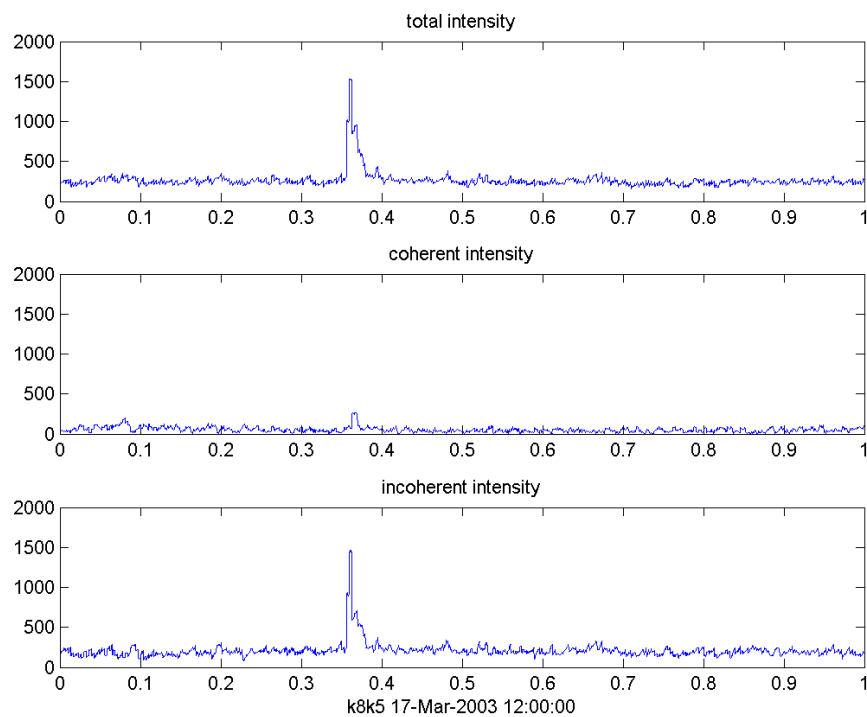
In Figure-2-5 through Figure-2-9, the data of acoustic power wave number spectra are compared for different current speeds. The experimental power spectra are also compared with the empirical spectra by Kolmogorov. The acoustically obtained power spectra agree very well each other. An expectation is one in Figure-2-6 which is from Station-1 to Station-5 and strong current velocity of 1.2 m/s. The spectrum slope of this case is 1.85 vs. 4.67 for Kolmogorov spectra. The case of current velocity = 1.2 m/s and the transmission pass St. K3 to St. K5 is stable and the spectral slope is approximately equal to the Kolmogorov spectra 4.67. For a small current velocity of 0.2 m/s acoustic transmission for K1 to K5 and K3 to K5 are both stable and have the acoustic power spectral slopes 4.24 and 4.44.

For almost all cases, the turbulences are fully developed. Only one case of K1 to K5 and a high current velocity of 1.2 m/s the turbulence is not fully developed.

This study will be continued further.

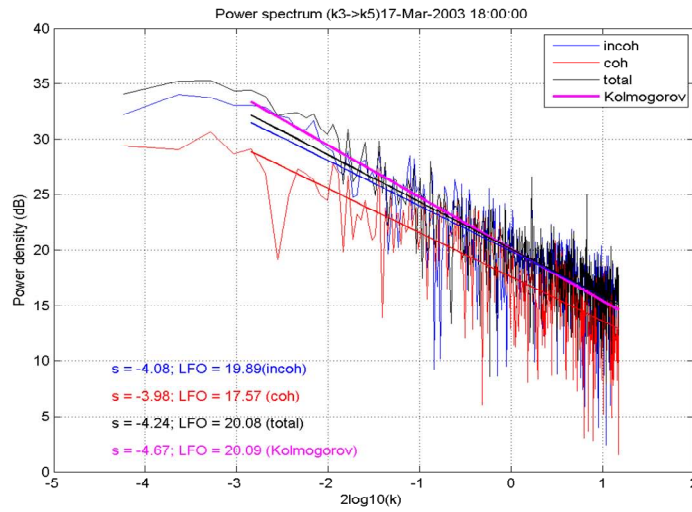


**Figure-2-3. Received signals at different tide height (K8->K5)**

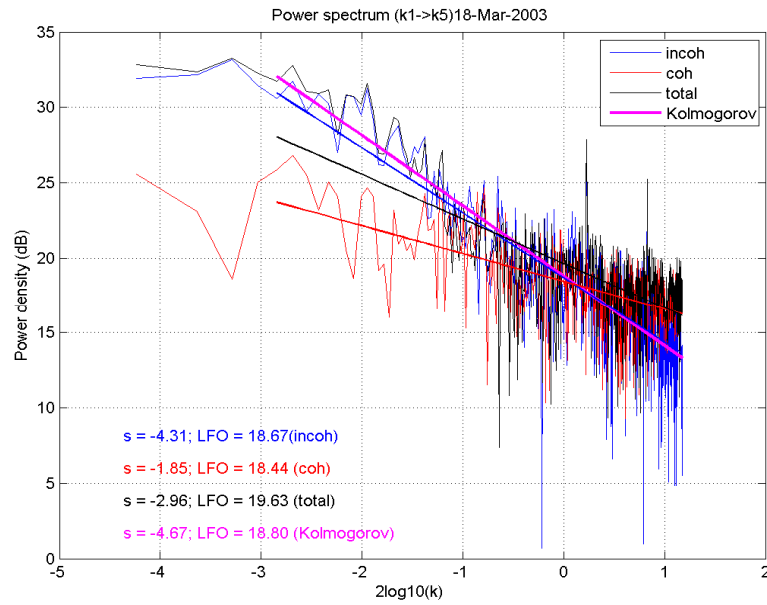


**Figure-2-4. The incoherent, coherent and total intensities of received signal**

**T = 1800 ( Current = 0.2 m/s ) K3 to K5**

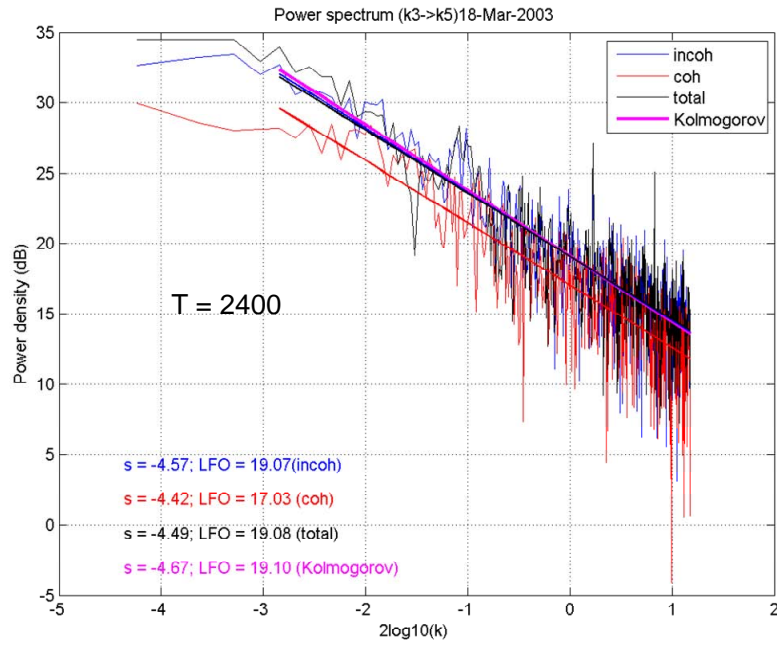


**T = 2400 Current = 1.2 m/s K1 to K5**

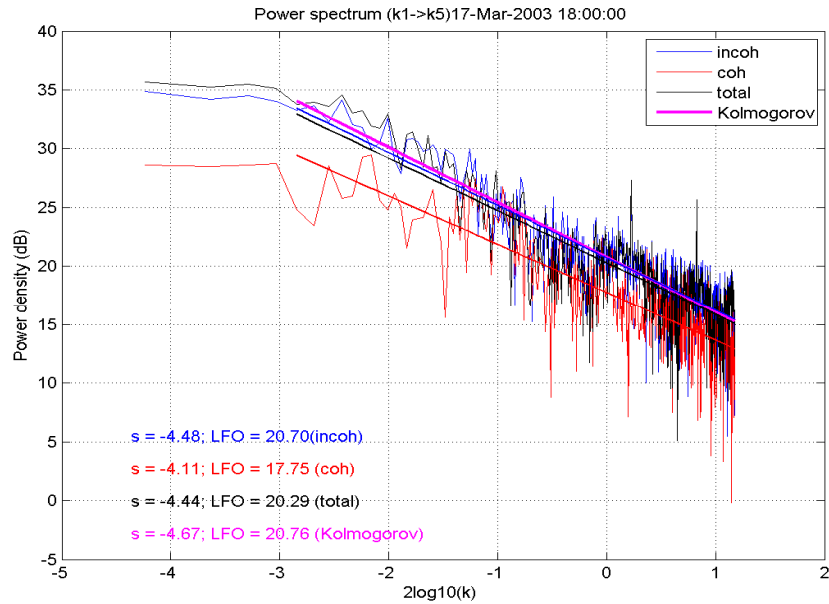


**Figure-2-5 (top) and -2-6 (bottom). The power density of acoustic wave received Vs. wave number for wave transmitted from Station 3 to 5 with current = 0.2 m/s; 2-6. for Station 1 to 5 Current = 1.2 m/s.**

**T =2400 ( Current = 1.2 m w/ Large Eddy)K3 to K5**



**Figure 2-7. Measured Acoustic Power Density vs. Wave Number, for K1 to K5 At High Tide with current velocity 0.2 m/s.**



**Figure-2-8. Measured Acoustic Power Density vs. Wave Number for K1 to K5.**

## RELATED PROJECTS

FY2009 gave us an extremely high quality and high quantity production. For the acoustics of bottom sediments Drs. Yamamoto and Turgut were given the NRL Alan Berman Award and the good news was distributed around the nation and the globe. Another high quality accomplishment is the accurate measurements of acoustic scattering from turbulence. The measurement of scattering from turbulence is so accurate that the forward and the inverse modeling provide the structure parameters of turbulence accurately.

### (1) The 2009 NRL Alan Barman Award Winning Paper

In-situ Measurements of Velocity Dispersion and Attenuation in New Jersey Shelf Sediments.  
Altan Turgut and Tokuo Yamamoto  
JASA August 2008

Not in a single paper in his twenty two geo-acoustic papers written by Morris Biot is the dispersive permeability treated. Dr. Yamamoto has been able to generalize the dispersion of the fast wave velocity of the Biot theory with the arbitrary pore size distributions. However, the experimental data (Turgut and Yamamoto, 2008) to test the Biot-Yamamoto theory (1988) have to be waited for twenty years. Dr. Turgut and the NRL Underwater Acoustics group acquired a quality sets of acoustic wave propagation through the silt sands on the New Jersey Shelf. The pore size distributions were measured by the Mercury Injection Methods developed and used by the Petroleum industry.

## PUBLICATIONS

A. Turgut and T. Yamamoto, “In situ measurements of velocity dispersion and attenuation in New Jersey Shelf sediments,” J. Acoust. Soc. Am. Express letter, August 2008.

A. Turgut and T. Yamamoto, “Measurements of acoustic wave velocities and attenuation in marine sediments,” J. Acoust. Soc. Am. 87, 2376–2382 (1990).

T. Yamamoto and A. Turgut, “Acoustic wave propagation through porous media with arbitrary pore size distributions,” J. Acoust. Soc. Am. 83, 1744–1751 (1988).

Turgut, A. Private Communications. , September 2009.

Yamaguchi, K. et al, A continuous mapping of tidal current structures in the Kanmon Strait, August 2004.